Trough Power Cycle Integration

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CSP Review Meeting
November 7, 2001

Team Members:

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Representing:

SunLab (NREL & Sandia), Kearney & Associates, Nexant,
Reflective Energies, Barber Nichols, ORMAT, Exergy, Bibb & Assoc.
DLR, FSI, CIEMAT, Fichtner, NIST

Purpose of Trough Power Cycle Integration Project

DOE Program Objectives:

- Identify best options for integrating a parabolic trough solar field into power plants, seeking
  - Increased effectiveness of solar thermal input
  - Better solar power plant performance
  - Reduced system cost

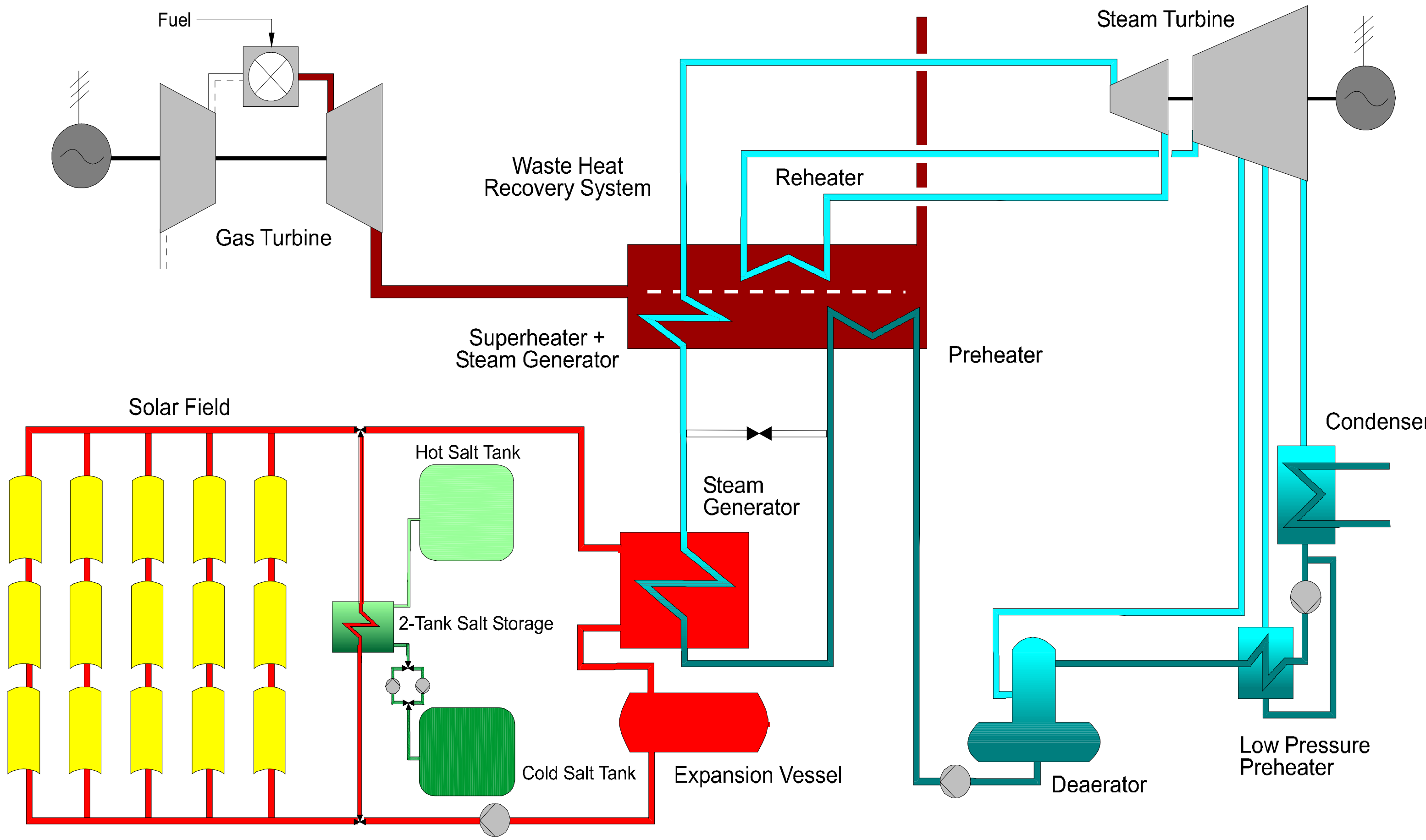
Power Integration Options Evaluated

- Combined Cycle (ISCCS, SEECOT)
- Organic Rankine Cycles
- Kalina Cycle
- Direct Steam Generation in Solar Field

Accomplishments

- Excellent analysis on ISCCS cycles, with direct applicability on GEF project designs
- Good understanding of ORC options, allowing optimization studies to progress
- Tracking of the direct steam generation work in Europe for future U.S. application if warranted

Integrated Solar Combined Cycle System

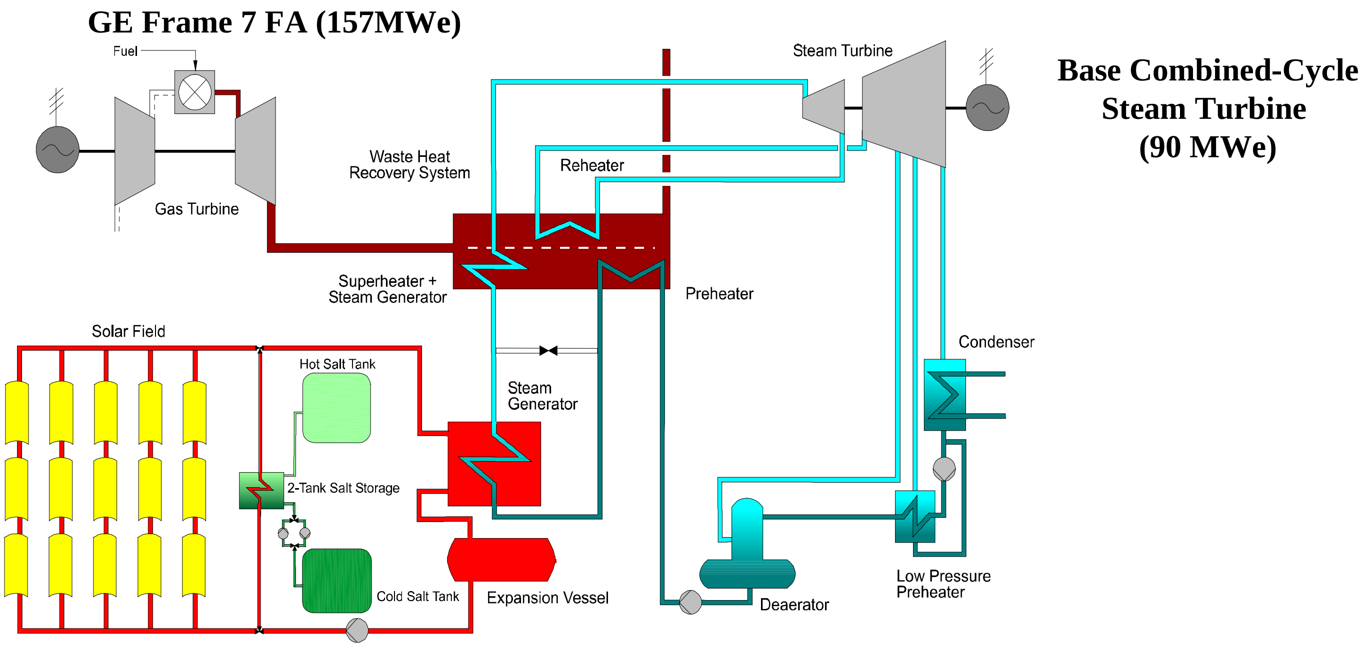


ISCCS Design Optimization
Integrated Solar Combined Cycle System

- **Objective:**
  - Develop optimization methodology for integrating the solar plant into combined cycle power plant.
  - Why attractive?
    - Solar steam taken to higher reheat temperatures with gas turbine exhaust
    - Incremental power block cost only $100/kW
    - Power block does not cycle daily as in solar only plant
    - Performance effectiveness of solar system and, to some extent, power block are slightly improved
- **Issues:**
  - If integration done poorly the plant can be less efficient than a fuel only combined-cycle plant.
  - Minimize impact on combined-cycle plant
  - Thermal storage
- **Approach:**
  - Contract with Nexant/Flabeg
  - Extensive GateCycle runs carried out in parametric analyses
  - International collaboration on TIPP Project (Flabeg, DLR)

Nexant/Flabeg USA Trough Phase I Work

ISCCS Optimization Study



Low Impact ISCCS (2 GE Frame 7FAs)

- 1-2% Annual Solar Contribution
- 40-42% Solar to Electric Efficiency
- Steam Turbine Increase 30 MWe (GT 314 MWe, ST 214MWe)
- Solar Field Size 200,000 m^2

High Impact ISCCS (1 Frame 7FA)

- 13% Annual Solar Contribution
- 29% Solar to Electric Efficiency
- Steam Turbine Increase 75 MWe (GT 157 MWe, ST 165 MWe)
- Solar Field Size 723,760 m^2

SEECOT

Solar Energy Enhanced Combustion Turbine

Solar absorption cooling of inlet air on gas turbine or combined cycle power plant

- Objective:
  - Evaluation of benefits and cost effectiveness of SEECOT cycle
- Approach:
  - Contract with Industrial Solar Technology
  - NREL support on GT/CC analysis
- Results:
  - Cooling GT inlet air allows more gas to be burned increasing plant capacity at slightly improved efficiency
  - Minimal benefit related to solar, but difficult to quantify

Organic Ranking Cycle
and Ammonia Water

- Objective:
  - Evaluate options for integration of trough solar plant with other power cycle technologies.
- Issues/Opportunities:
  - High value markets for solar power in smaller size plants
  - Improvements in geothermal & biomass power cycle technologies create opportunities for integration with trough solar technology.
  - Thermal storage available for solar plants operating at 300C
  - Lower temperatures mean lower efficiency
  - Need to design plants to minimize O&M requirements
- Approach:
  - Contracts with Reflective Energies (Bibb & Associates), Barber Nichols, Exergy, NIST
  - SunLab Study

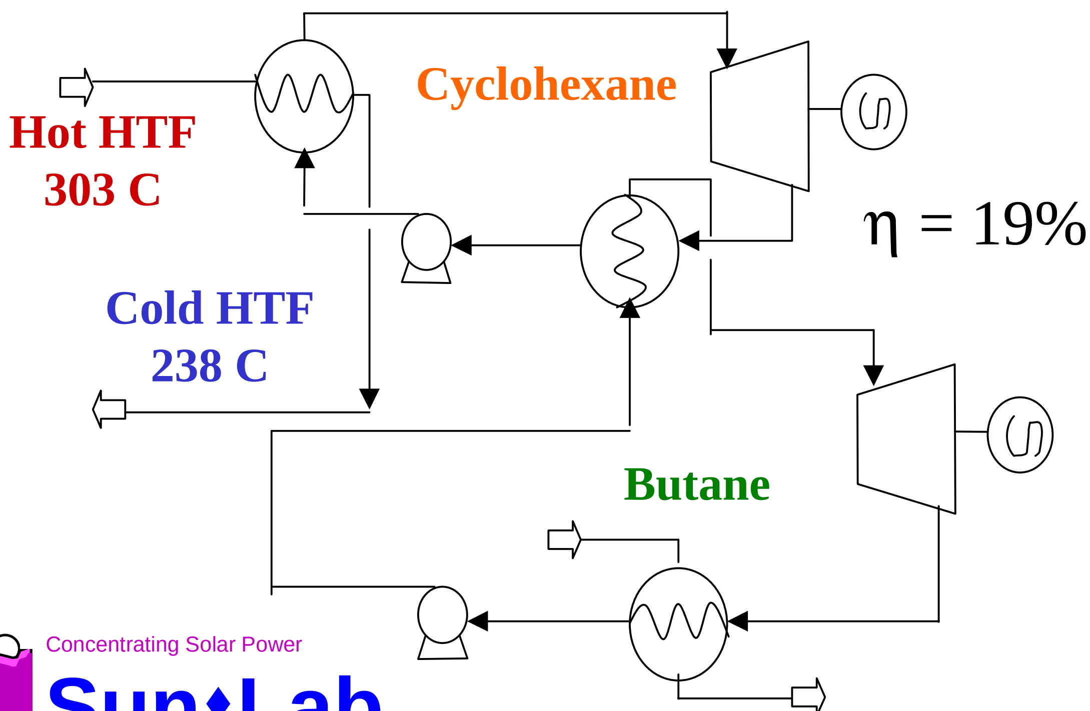
Reflective Energies USA Trough Phase I Work

Solar Trough Organic Rankine Electric System

STORES

- 10 MWe Cascade ORC
- Air Cooled
- Uses Caloria HTF for Thermal Storage
- ORC Optimized for Trough Temperatures

Reflective Energies



Results

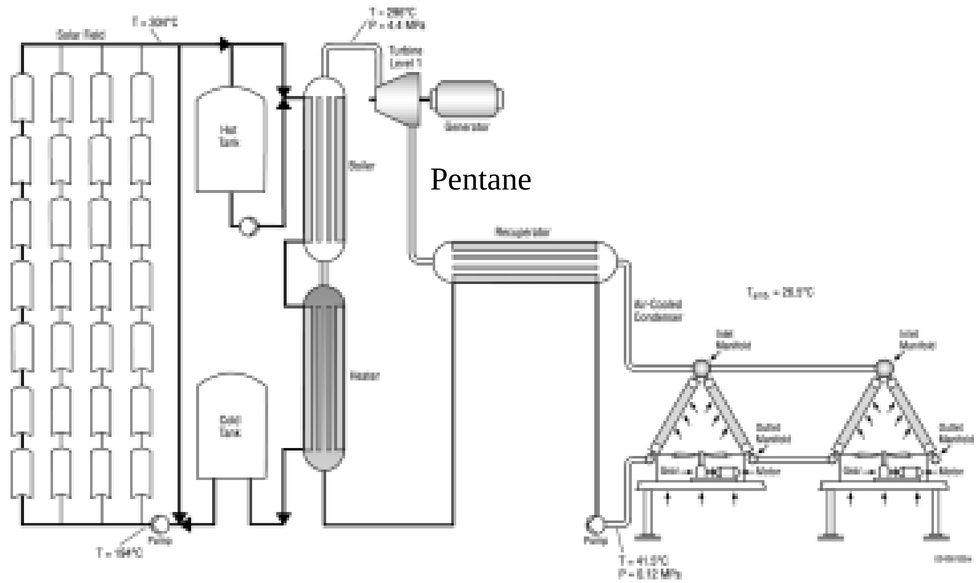
Capital Cost $4500/kWe

LEC 22-31 ¢/kWh

SunLab Trough ORC Analysis

2nd Plant Economics

- **Power Cycle:**
  - 1 MWe organic Rankine cycle
  - recuperated
  - air cooled
  - 22.5% efficiency
  - \$1700/kW_e (Barber Nichols)
- **Solar Field:**
  - ~20,000 m^2 parabolic trough
  - 193-304C operating temperature
  - non-evacuated Cermet receiver
  - \$200/m^2
- **Thermal Storage:**
  - 2-Tank Caloria HT-43
  - 9 hours of thermal storage
  - Nexant TS cost model
- **Annual Performance:**
  - capacity factor @ 1 MWe: 53%
  - solar to electric efficiency: 8.4%

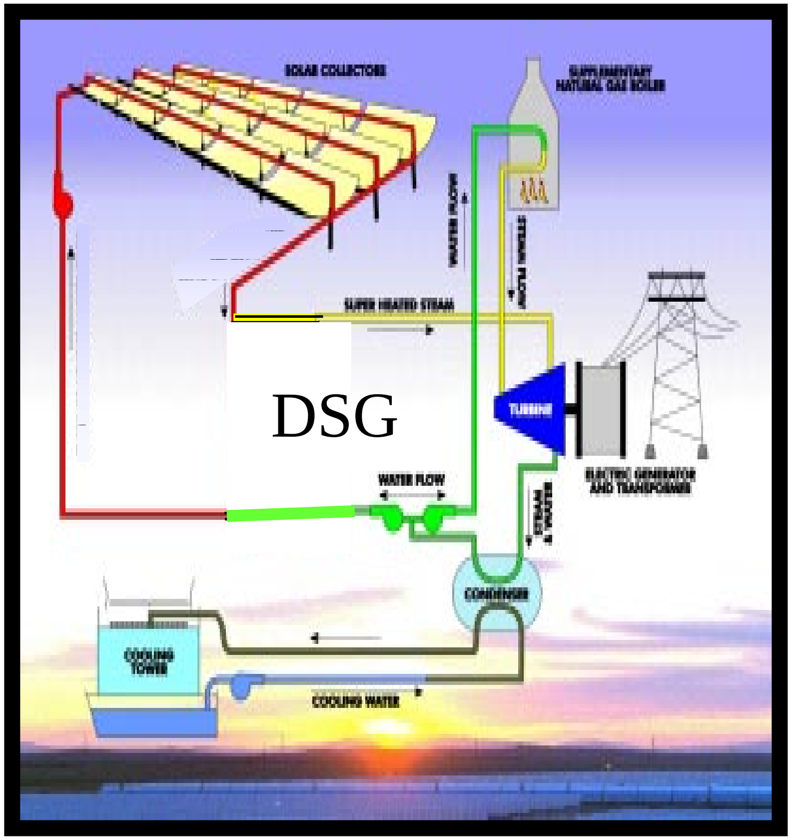


- **Economic Assumptions:**
  - 20 year lifetime
  - Insurance: 0.5% of capital cost
  - O&M cost: 2.5¢/kWh
- **Levelized Energy Cost: 20¢/kWh**

Future Costs < 15 ¢/kWh
(after 10s of systems)

Direct Steam Generation

- Objective: Evaluate parabolic trough solar field that generates high temperature and pressure steam directly in the collectors.
- Advantage:
  - Elimination of HTF system
  - Increase solar field operating temperature
- Issues:
  - Maintaining steam quality to turbine Reduce pumping parasitics
  - with transient resource conditions
  - High pressure steam in solar field
  - Flow control in multi-loop solar field
  - No thermal storage option
- Approach: European test in Spain



Summary of Key Results

- Excellent work on optimization of ISCCS power cycle configurations, leading to better commercial systems options and improved performance projections
- Good foundation work on ORC systems, setting stage for final optimizations
- Monitoring of direct steam generation option